DTIC FILE COPY

(4)

US Army Corps of Engineers
Hydrologic Engineering Center

AD-A225 777

Hydrologic Aspects of Flood Warning - Preparedness Programs

Technical Paper No. 131
August 1990

Approved for Public Release. Distribution is Unlimited.

Papers in this series have resulted from technical activities of the Hydrologic Engineering Center. Versions of some of these have been published in technical journals or in conference proceedings. The purpose of this series is to make the information available for use in the Center's training program and for distribution within the Corps of Engineers.

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

The contents of this report are not to be used for advertising, publication, or promotional purposes. Citation of trade names does not constitute an official endorsement or approval of the use of such commercial products.

Hydrologic Aspects of Flood Warning - Preparedness Programs

Harry W. Dotson*, M.ASCE and John C. Peters*, M.ASCE

Abstract

A reliable flood-threat recognition system is a vital component of a sound flood warning-preparedness program. Fundamental questions associated with the development of a flood-threat recognition system are: what warning times can be achieved, and how reliable will the warnings be? Answers to these questions depend on watershed and storm characteristics, and the flood-threat recognition method being considered. The tradeoff between warning time and warning reliability is illustrated, and methods for estimating warning time are discussed.

Introduction

Flood warning and preparedness programs involve flood-threat recognition, warning dissemination, emergency response and post-flood recovery. The design and implementation of a sound, cost-effective program and the determination of the scope of the program depend substantially on the supporting hydrologic analyses. An important aspect of the hydrologic analyses is the development of a flood-threat recognition system. The analysis includes the evaluation of flood warning times, warning criteria, and the reliability of the warning.

Warning Time and Reliability

The concept of warning time is illustrated in Figure 1 (FIACWD, 1989). As indicated, maximum potential warning time (T_{wp}) is the time from the first indication of precipitation to the time flooding begins. Use of time (T_{wp}) as the actual warning time (T_w) would be totally unreliable because it would indicate that it floods every time it rains. There must be a flood recognition time (T_r) which is the time required for specific warning criteria to indicate flooding is imminent. The criteria could be that a specific amount of precipitation has occurred or that a stream has reached a specified stage. The longer the flood recognition time, the

---

*Hydraulic Engineer, US Army Corps of Engineers, Hydrologic Engineering Center, 609 Second Street, Davis, CA 95616. Presented at the ASCE Hydraulics Division 1990 National Conference on Hydraulic Engineering, August 1990, San Diego, CA.

warning time. However, one must be aware of the tradeoffs between warning time and warning reliability.

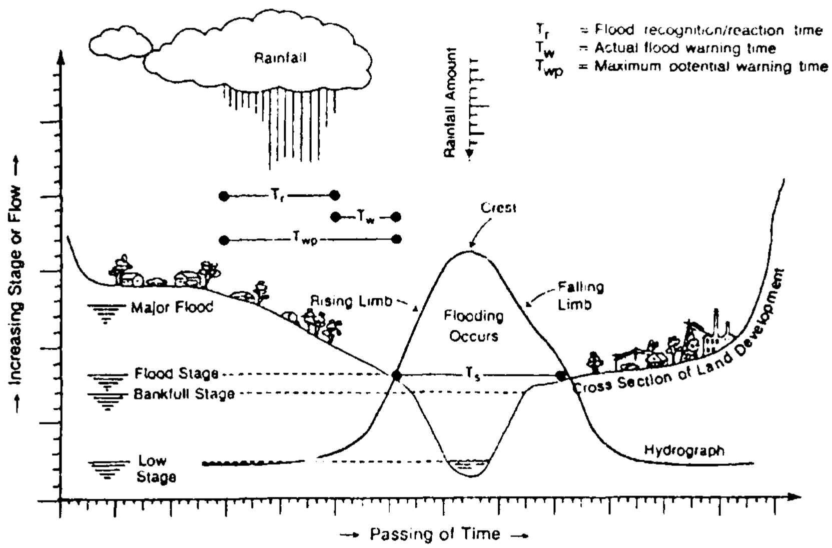

Figure 1. Illustration of Flood Warning Time

Consider Figure 2, which illustrates aspects of reliability. Sets of storm events are labeled {A}, {B}, {C} and {D}, where:

{A} = storm events that cause flooding
{B} = storm events that do not cause flooding
{C} = storm events that cause flooding but for which warnings are not issued
{D} = storm events that do not cause flooding but for which warnings are issued

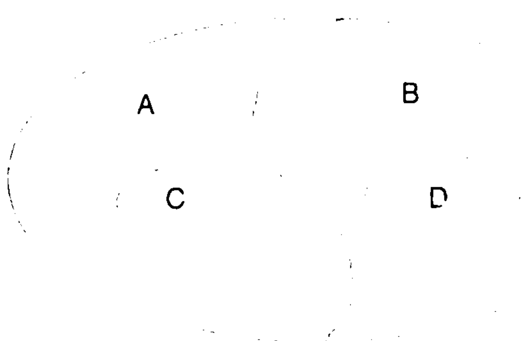

Figure 2. Reliability of Flood Warnings

The goal of a warning system is to minimize both {C} and {D}. Events from {C} can cause damage and loss of life that could possibly be prevented; events from {D} increase the likelihood that future warnings will be ignored. Alternative warning systems will be reflected by different configurations of {C} and {D}. The basis for a warning can range from measured stage at an index gage to results of a rainfall-runoff model that incorporate recent rain data and possibly estimates of future rainfall. Although the more sophisticated warning systems will tend to provide longer lead times, their reliability may not necessarily be greater than that associated with simpler systems. Both warning time and reliability should be evaluated when analyzing alternative warning systems

The tradeoff between lead time (warning time) and warning reliability can be illustrated by considering a simple threshold-stage method of warning, as illustrated in Figure 3. The warning stage is sensed at location A. The primary flood threat is downstream at location B. The problem is to choose a threshold (index) stage for location A such that when that stage is exceeded, a warning for flooding at location B is to be issued. It is desired that the lead time to prepare for the flood threat be as long as possible. The lower the index stage at A, presumably the more lead time will be afforded. However, if the threshold stage is too low, there will be too many false warnings, so that genuine warnings will not be heeded. In terms of Figure 2, as {C} is made smaller, {D} becomes larger.

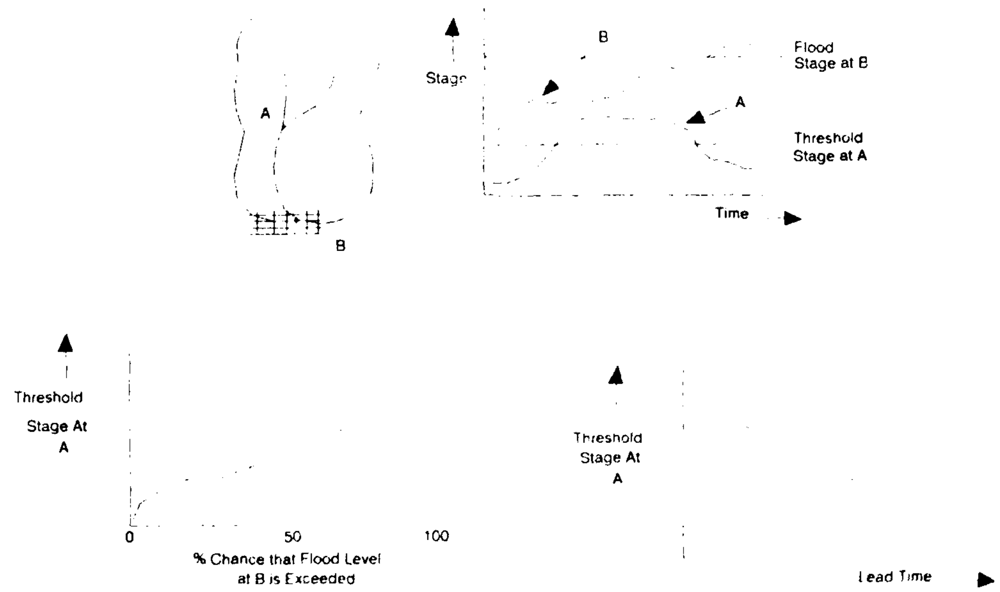

Figure 3. Lead Time Versus Warning Reliability

Illustration of Flood Warning and Reliability

To illustrate the tradeoff between warning time and reliability that is implicit in a flood warning system, consider a situation like that in Figure 3 in which a threshold stage at an index gage is to be used to trigger an alarm that warns of the impending exceedance of flood stage at a damage center. Although most flood warning systems are more sophisticated than this, analysis of a simple system can provide insights that have broader implications.

The basin used in this illustration is part of the Central Great Plains Experimental Watershed near Hastings, Nebraska (USDA, undated). In particular, discharge data collected over a 29-year period (1939-1967) at three gages on the west branch of Beaver Creek were used. The locations are labeled W3, W8 and W11 in Figure 4a. The drainage areas at these locations are very small and warning times will be very short. However, the intent of this analysis is to illustrate concepts rather than a practical design. and the available data is well suited to this purpose.

Assume that location W11 is the damage center for which a warning is to be issued, and that flood stage at W11 corresponds to a discharge of 300 cfs. This discharge was exceeded for 16 events during the 29-year period of record. Locations W3 and W8 will be considered individually as index locations for triggering a warning. That is, when a threshold discharge is exceeded at the index location, a warning is issued. The problem is to determine the threshold discharge to be used, and to assess associated warning time and reliability.

Period-of-record discharge data at a 15-minute interval for the three locations were acquired. The data were processed to determine events that excced the flood discharge (300 cfs) at W11, and to determine threshold discharge exceedances at W3 and W8. Table

Table 1
Warning Time Analysis for a Threshold Q of 200 cfs at W8

Flood discharge at W11 = 300 cfs.

Date & Time of Flood at W11	Peak Q at W11	Time of Peak Q W11	Thresh. Q at W8 Exceeded?	Time of Exceed. Thresh. Q	Potential Warning Time (hr:min)
12 MAY 44 0315	394	0330	yes	0115	2:00
25 AUG 44 1045	343	1515	yes	1100	-:15
16 JUL 45 2045	333	2100	yes	1745	3:00
9 JUN 49 0030	374	0145	yes	2045 [2]	3:45
20 SEP 50 0115	730	0300	yes	2230	2:45
1 JUL 51 2045	1147	2215	yes	1930	1:15
10 JUL 51 0815	918	0900	yes	0630	1:45
14 JUL 52 0400	1063	0430	yes	0115	2:45
7 JUN 53 1815	680	2000	yes	1745	:30
22 MAY 54 2315	999	0200 [1]	yes	2300	:15
27 MAY 54 0330	325	0345	yes	2345	3:45
15 JUN 57 1730	1459	2115	yes	1215	5:15
29 AUG 57 0045	414	0130	yes	0130	-:45
3 JUL 59 2130	838	2400	yes	2115	:15
27 MAR 60 1645	365	1745	yes	1315	3:30
15 MAY 60 2230	811	0115 [1]	yes	2230	:00

[1] Next day.
[2] Previous day

16 flood events in 29 years
Number of events threshold discharge (200 cfs) was exceeded: 45
Reliability = 16/45 x 100 = 36%

1 illustrates results for a threshold dischage of 200 cfs at W8. The first three columns pertain to the flood event at W11; the last three columns refer to the exceedance of the thresholddischarge at W8. In this illustration, the threshold discharge was exceeded during all 16 flood events. The potential warning time associated with the events is shown in the last column. For two of the events, the time is negative.

As noted at the bottom of Table 1, the threshold discharge was exceeded 45 times during the 29 years of record, which means that a false warning would have been generated 29 times. The realiability of the warning mechanism, that is, the percent of true warnings to total warnings, is 16/45 x 100. or 36 percent. As may be noted from the table, a warning time ≥ 1 hour would have been provided for 10 of the 16, or 63 percent of the flood events. A warning time ≥ 30 minutes would have been provided for 69 percent of the events. The analysis illustrated in Table 1 was also applied with threshold discharges

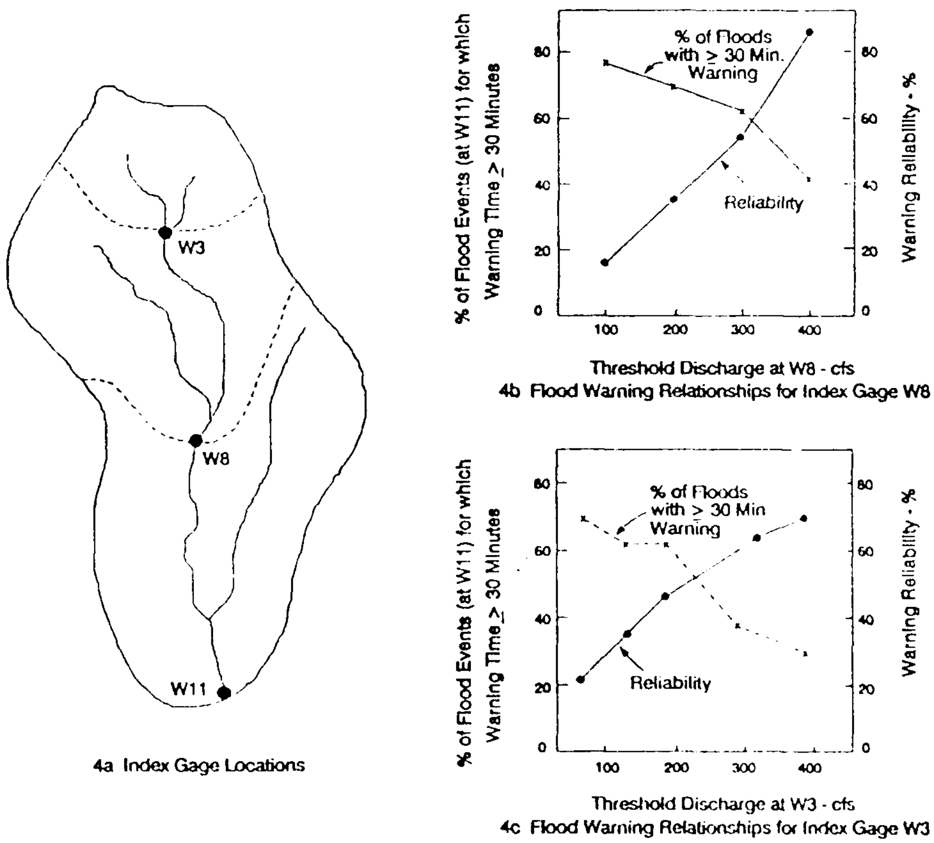

Figure 4. Beaver Creek Watershed

at W8 of 100, 300 and 400 cfs. Figure 4b shows forecast reliability and occurrence of at least a 30-minute warning time, both as a function of threshold discharge at W8. Figure 4c shows results for W3.

The inverse relationship between warning reliability and warning occurrence is readily apparent in Figures 4b and 4c. Suppose that it were desired to have a warning reliability of 70 percent, meaning that 7 out of 10 warnings would be for actual flood events. From Figure 4b, the corresponding threshold discharge at W8 is about 350 cfs and the percent

of flood events for which a warning time $\geq$ 30 minutes is provided is 53 percent. That is, a warning time $\geq$ 30 minutes would be provided for only about half the flood events, and 3 out of 10 warnings would be erroneous. These are not very impressive figures, and such a warning system would obviously be far less than adequate.

By comparison, Figure 4c indicates that a 70 percent reliability could be achieved with a threshold discharge of 400 cfs at W3, for which a warning time $\geq$ 30 minutes would be provided for only 31 percent of the flood events. For this level of reliability, index location W8 is the better of the two locations.

Estimation of Flood Warning Time

Flood-threat recognition essentially involves real-time sampling of characteristics of a storm event and forecasting the probable near-term runoff response. The more variability associated with the event being sampled, the more difficulty there is in obtaining an adequate sample and the more uncertain the forecast.

Key variables upon which warning time depends include: (1) spatial variability of precipitation, (2) temporal variability of precipitation, (3) rainfall-runoff response characteristics of the watershed and (4) antecedent soil moisture conditions. Storm rainfall, and consequently warning time, typically exhibit substantial variability. To properly evaluate the potential warning time for a watershed, a set of storms should be analyzed that reflects such variability. Warning time can then be defined in terms of a median value and a standard deviation or some other measure of variability.

Warning time for a specific historical storm event can be estimated using a rainfall-runoff forecast model such as HEC-IF (Peters, 1985). The model accounts for precipitation and streamflow that has occurred up to the specified time-of-forecast and simulates streamflow into the future. Successive times-of-forecast can be evaluated until the simulated future runoff exceeds flood stage. The time between the time-of-forecast and the time when flooding begins represents an estimate of the gross warning time for the event being analyzed. An estimated time for collecting and analyzing real-time data during an actual storm would need to be estimated and subtracted from the gross warning time. If climatological forecasts had indicated a significant probability of future rainfall, such rainfall could be incorporated in the forecast and a longer warning time achieved. However, quantitative estimates of future precipitation are notoriously uncertain.

Ideally the analysis as described would be made for a number of historical events, and the median value and variability of warning determined. If there were no historical precipitation data for the basin, it would be reasonable to transpose rainfall information from within a hydrometeorologically homogeneous region. If no concurrent precipitation and streamflow data were available for a basin, there would, of course, be additional uncertainty associated with lack of data with which to calibrate the rainfall-runoff model.

References

1. USDA, Agricultural Research Service, The Central Great Plains Experimental Watershed, A Summary Report of 30 Years of Hydrologic Research, (undated report).

2. Federal Interagency Advisory Committee on Water Data (FIACWD), Hydrology Subcommittee, Guidelines on Community Local Flood Warning and Response Systems, 1985.

3. Peters, J., and P. Ely, Flood-Runoff Forecasting with HEC1F, Water Resources Bulletin, 21 (1), 1985.

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1a REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b RESTRICTIVE MARKINGS
2a SECURITY CLASSIFICATION AUTHORITY	3 DISTRIBUTION/AVAILABILITY OF REPORT
2b DECLASSIFICATION/DOWNGRADING SCHEDULE	
4 PERFORMING ORGANIZATION REPORT NUMBER(S) Technical Paper No. 131	5 MONITORING ORGANIZATION REPORT NUMBER(S)
6a NAME OF PERFORMING ORGANIZATION Hydrologic Engineering Center 6b OFFICE SYMBOL (If applicable) CEWRC-HEC	7a NAME OF MONITORING ORGANIZATION Water Resources Support Center
6c ADDRESS (City, State, and ZIP Code) 609 Second St. Davis, CA 95616	7b ADDRESS (City, State, and ZIP Code) Casey Building, 2594 Fort Belvoir, Virginia 22060
8a NAME OF FUNDING/SPONSORING ORGANIZATION 8b OFFICE SYMBOL (If applicable)	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c ADDRESS (City, State, and ZIP Code)	10 SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO / PROJECT NO / TASK NO / WORK UNIT ACCESSION NO

11 TITLE (Include Security Classification)
Hydrologic Aspects of Flood Warning - Preparedness Programs

12 PERSONAL AUTHOR(S)
Harry W. Dotson and John C. Peters

13a TYPE OF REPORT	13b TIME COVERED	14 DATE OF REPORT (Year, Month, Day)	15 PAGE COUNT
Technical Paper	FROM ______ TO ______	August 1990	7

16 SUPPLEMENTARY NOTATION

17 COSATI CODES			18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Flood threat recognition, flood warning time, warning reliability, historical storm events, forecasting, rainfall-runoff modeling, HEC-1F program.

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

A reliable flood-threat recognition system is a vital component of a sound flood warning-preparedness program. Fundamental questions associated with the development of a flood-threat recognition system are: what warning times can be achieved, and how reliable will the warnings be? Answers to these questions depend on watershed and storm characteristics, and the flood-threat recognition method being considered. The tradeoff between warning time and warning reliability is illustrated, and methods for estimating warning time are discussed.

20 DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21 ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a NAME OF RESPONSIBLE INDIVIDUAL Darryl W. Davis, Director, HEC	22b TELEPHONE (Include Area Code) (916) 756-1104 22c OFFICE SYMBOL CEWRC-HEC

DD Form 1473, JUN 86 Previous editions are obsolete SECURITY CLASSIFICATION OF THIS PAGE

UNCLASSIFIED

TECHNICAL PAPER SERIES
($2.00 per paper)

TP-1 Use of Interrelated Records to Simulate Streamflow
TP-2 Optimization Techniques for Hydrologic Engineering
TP-3 Methods of Determination of Safe Yield and Compensation Water from Storage Reservoirs
TP-4 Functional Evaluation of a Water Resources System
TP-5 Streamflow Synthesis for Ungaged Rivers
TP-6 Simulation of Daily Streamflow
TP-7 Pilot Study for Storage Requirements for Low Flow Augmentation
TP-8 Worth of Streamflow Data for Project Design - A Pilot Study
TP-9 Economic Evaluation of Reservoir System Accomplishments
TP-10 Hydrologic Simulation in Water-Yield Analysis
TP-11 Survey of Programs for Water Surface Profiles
TP-12 Hypothetical Flood Computation for a Stream System
TP-13 Maximum Utilization of Scarce Data in Hydrologic Design
TP-14 Techniques for Evaluating Long-Term Reservoir Yields
TP-15 Hydrostatistics - Principles of Application
TP-16 A Hydrologic Water Resource System Modeling Techniques
TP-17 Hydrologic Engineering Techniques for Regional Water Resources Planning
TP-18 Estimating Monthly Streamflows Within a Region
TP-19 Suspended Sediment Discharge in Streams
TP-20 Computer Determination of Flow Through Bridges
TP-21 An Approach to Reservoir Temperature Analysis
TP-22 A Finite Difference Method for Analyzing Liquid Flow in Variably Saturated Porous Media
TP-23 Uses of Simulation in River Basin Planning
TP-24 Hydroelectric Power Analysis in Reservoir Systems
TP-25 Status of Water Resource Systems Analysis
TP-26 System Relationships for Panama Canal Water Supply
TP-27 System Analysis of the Panama Canal Water Supply
TP-28 Digital Simulation of an Existing Water Resources System
TP-29 Computer Applications in Continuing Education
TP-30 Drought Severity and Water Supply Dependability
TP-31 Development of System Operation Rules for an Existing System by Simulation
TP-32 Alternative Approaches to Water Resource System Simulation
TP-33 System Simulation for Integrated Use of Hydroelectric and Thermal Power Generation
TP-34 Optimizing Flood Control Allocation for a Multipurpose Reservoir
TP-35 Computer Models for Rainfall-Runoff and River Hydraulic Analysis
TP-36 Evaluation of Drought Effects at Lake Atitlan
TP-37 Downstream Effects of the Levee Overtopping at Wilkes-Barre, PA, During Tropical Storm Agnes
TP-38 Water Quality Evaluation of Aquatic Systems
TP-39 A Method for Analyzing Effects of Dam Failures in Design Studies
TP-40 Storm Drainage and Urban Region Flood Control Planning
TP-41 HEC-5C, A Simulation Model for System Formulation and Evaluation
TP-42 Optimal Sizing of Urban Flood Control Systems
TP-43 Hydrologic and Economic Simulation of Flood Control Aspects of Water Resources Systems
TP-44 Sizing Flood Control Reservoir Systems by Systems Analysis
TP-45 Techniques for Real-Time Operation of Flood Control Reservoirs in the Merrimack River Basin
TP-46 Spatial Data Analysis of Nonstructural Measures
TP-47 Comprehensive Flood Plain Studies Using Spatial Data Management Techniques
TP-48 Direct Runoff Hydrograph Parameters Versus Urbanization
TP-49 Experience of HEC in Disseminating Information on Hydrological Models
TP-50 Effects of Dam Removal: An Approach to Sedimentation
TP-51 Design of Flood Control Improvements by Systems Analysis: A Case Study
TP-52 Potential Use of Digital Computer Ground Water Models
TP-53 Development of Generalized Free Surface Flow Models Using Finite Element Techniques
TP-54 Adjustment of Peak Discharge Rates for Urbanization
TP-55 The Development and Servicing of Spatial Data Management Techniques in the Corps of Engineers
TP-56 Experiences of the Hydrologic Engineering Center in Maintaining Widely Used Hydrologic and Water Resource Computer Models
TP-57 Flood Damage Assessments Using Spatial Data Management Techniques
TP-58 A Model for Evaluating Runoff-Quality in Metropolitan Master Planning
TP-59 Testing of Several Runoff Models on an Urban Watershed
TP-60 Operational Simulation of a Reservoir System with Pumped Storage
TP-61 Technical Factors in Small Hydropower Planning
TP-62 Flood Hydrograph and Peak Flow Frequency Analysis
TP-63 HEC Contribution to Reservoir System Operation
TP-64 Determining Peak-Discharge Frequencies in an Urbanizing Watershed: A Case Study
TP-65 Feasibility Analysis in Small Hydropower Planning
TP-66 Reservoir Storage Determination by Computer Simulation of Flood Control and Conservation Systems
TP-67 Hydrologic Land Use Classification Using LANDSAT
TP-68 Interactive Nonstructural Flood-Control Planning
TP-69 Critical Water Surface by Minimum Specific Energy Using the Parabolic Method
TP-70 Corps of Engineers Experience with Automatic Calibration of a Precipitation-Runoff Model

TP-71 Determination of Land Use from Satellite Imagery for Input to Hydrologic Models
TP-72 Application of the Finite Element Method to Vertically Stratified Hydrodynamic Flow and Water Quality
TP-73 Flood Mitigation Planning Using HEC-SAM
TP-74 Hydrographs by Single Linear Reservoir Model
TP-75 HEC Activities in Reservoir Analysis
TP-76 Institutional Support of Water Resource Models
TP-77 Investigation of Soil Conservation Service Urban Hydrology Techniques
TP-78 Potential for Increasing the Output of Existing Hydroelectric Plants
TP-79 Potential Energy and Capacity Gains from Flood Control Storage Reallocation at Existing U. S. Hydropower Reservoirs
TP-80 Use of Non-Sequential Techniques in the Analysis of Power Potential at Storage Projects
TP-81 Data Management Systems for Water Resources Planning
TP-82 The New HEC-1 Flood Hydrograph Package
TP-83 River and Reservoir Systems Water Quality Modeling Capability
TP-84 Generalized Real-Time Flood Control System Model
TP-85 Operation Policy Analysis: Sam Rayburn Reservoir
TP-86 Training the Practitioner. The Hydrologic Engineering Center Program
TP-87 Documentation Needs for Water Resources Models
TP-88 Reservoir System Regulation for Water Quality Control
TP-89 A Software System to Aid in Making Real-Time Water Control Decisions
TP-90 Calibration, Verification and Application of a Two-Dimensional Flow Model
TP-91 HEC Software Development and Support
TP-92 Hydrologic Engineering Center Planning Models
TP-93 Flood Routing Through a Flat, Complex Flood Plain Using a One-Dimensional Unsteady Flow Computer Program
TP-94 Dredged-Material Disposal Management Model
TP-95 Infiltration and Soil Moisture Redistribution in HEC-1
TP-96 The Hydrologic Engineering Center Experience in Nonstructural Planning
TP-97 Prediction of the Effects of a Flood Control Project on a Meandering Stream
TP-98 Evolution in Computer Programs Causes Evolution in Training Needs: The Hydrologic Engineering Center Experience
TP-99 Reservoir System Analysis for Water Quality
TP-100 Probable Maximum Flood Estimation - Eastern United States
TP-101 Use of Computer Program HEC-5 for Water Supply Analysis
TP-102 Role of Calibration in the Application of HEC-6
TP-103 Engineering and Economic Considerations in Formulating
TP-104 Modeling Water Resources Systems for Water Quality
TP-105 Use of a Two-Dimensional Flow Model to Quantify Aquatic Habitat
TP-106 Flood-Runoff Forecasting with HEC-1F
TP-107 Dredged-Material Disposal System Capacity Expansion
TP-108 Role of Small Computers in Two-Dimensional Flow Modeling
TP-109 One-Dimensional Model For Mud Flows
TP-110 Subdivision Froude Number
TP-111 HEC-5Q: System Water Quality Modeling
TP-112 New Developments in HEC Programs for Flood Control
TP-113 Modeling and Managing Water Resource Systems for Water Quality
TP-114 Accuracy of Computed Water Surface Profiles - Executive Summary
TP-115 Application of Spatial-Data Management Techniques in Corps Planning
TP-116 The HEC's Activities in Watershed Modeling
TP-117 HEC-1 and HEC-2 Applications on the MicroComputer
TP-118 Real-Time Snow Simulation Model for the Monongahela River Basin
TP-119 Multi-Purpose, Multi-Reservoir Simulation on a PC
TP-120 Technology Transfer of Corps' Hydrologic Models
TP-121 Development, Calibration and Application of Runoff Forecasting Models for the Allegheny River Basin
TP-122 The Estimation of Rainfall for Flood Forecasting Using Radar and Rain Gage Data
TP-123 Developing and Managing a Comprehensive Reservoir Analysis Model
TP-124 Review of the U.S. Army Corps of Engineering Involvement With Alluvial Fan Flooding Problems
TP-125 An Integrated Software Package for Flood Damage Analysis
TP-126 The Value and Depreciation of Existing Facilities: The Case of Reservoirs
TP-127 Floodplain-Management Plan Enumeration
TP-128 Two-Dimensional Floodplain Modeling
TP-129 Status and New Capabilities of Computer Program HEC-6: "Scour and Deposition in Rivers and Reservoirs"
TP-130 Estimating Sediment Delivery and Yield on Alluvial Fans
TP-131 Hydrologic Aspects of Flood Warning - Preparedness Programs